Evaluating the accuracy of LiDAR in forested areas and understanding the variability of snow depth with respect the canopy – UW-SLF collaboration

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Introduction & Driving Questions

We plan to evaluate ASO LiDAR accuracy in forests using: 1.) TLS SnowEx data and 2.) SLF manual snow depth measurements. Furthermore, we are using already existing Airborne LiDAR observations from various climates to understand the spatial variability in forested and open areas. Particularly, we have focused on categorizing forest edges and looking at how snow depth distributions vary based on the forest architecture. Together, we're specifically motivated to answer:

1. How do ground observations (TLS & manual snow depth measurements) compare to ASO snow depth in forests?
2. How is accuracy related to distance from canopy?
3. Do unique snow depth distributions appear along the forest edge when a hypothetical model grid cell (Figure 1) is broken into north facing edges and south facing edges?
   a. Does the edge effect depend on climate?
4. How do snow depth distributions change based on:
   a. How we categorize the forest edge?
      - *Determine the forest edge based on: Distance from Canopy, SVF, and/or Tree Height*
   b. The size of the bounding box we're evaluating?

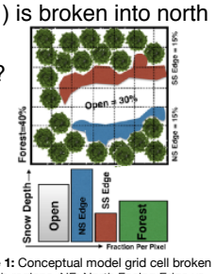
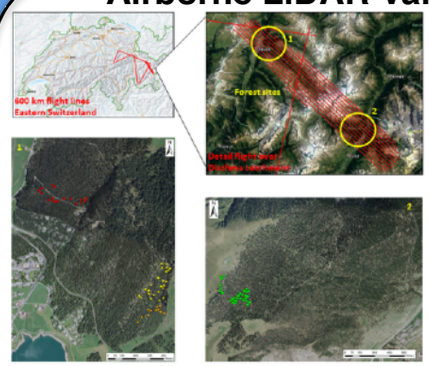


Figure 1: Conceptual model grid cell broken into sub regions. NF: North Facing Edge vs. SF: South Facing Edge

Airborne LiDAR Validation Data



Swiss Data:

- Two Snow On Flights (20 & 31 March 2017)
- Same Sensors as ASO
- Altitude: ~2000 m above forest (~10 pts./m2)
- At site 1: 1-m canopy height model with 30 pts/m2 LiDAR data
- 11,000 Manual Snow Depth (HS) Measurements Taken in 8 different cardinal directions around trees
- 20 x 20 m plots, 132 measurements/plot
- 20 snow depth measurements per transect

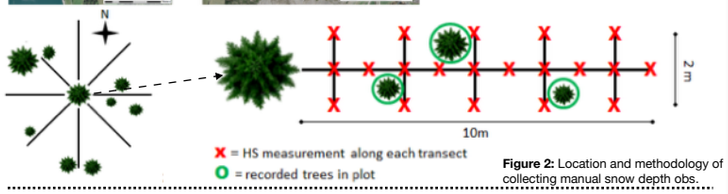
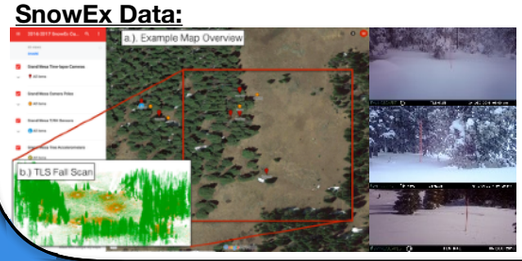


Figure 2: Location and methodology of collecting manual snow depth obs.

SnowEx Data:



TLS Site K Data

- Terrestial LiDAR Scans
  - *(Figure 3. b.) provided by Boise State's BCAL Group*
- Geo-located Snow Depth Poles and Time-Lapse Photos
- Judd Acoustic Snow Depth Sensors

Figure 3: Example of obs. from SnowEx TLS site K

Airborne LiDAR Accuracy in Forests

Questions

1. How do snow depth distributions from TLS/manual measurements and ASO agree for the sub-regions defined in Figure 1?
2. Do TLS and ASO agree per 3-m pixel in a scenario where the tree is ~60% of the 3x3-m pixel

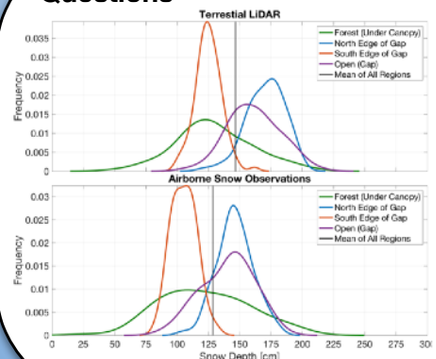


Figure 5: Hypothetical snow depth distributions, synthetic data

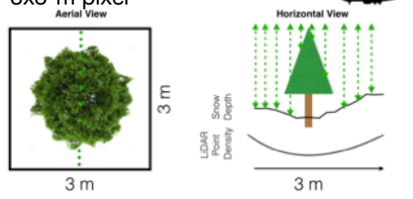


Figure 5: Potential errors in 3-m data as the result of tree wells

Spatial Variability of Forest Snow Depth

While SnowEx and SLF LiDAR data continue to be processed we're exploring forest edge effects using already available LiDAR data from 4 different environments.

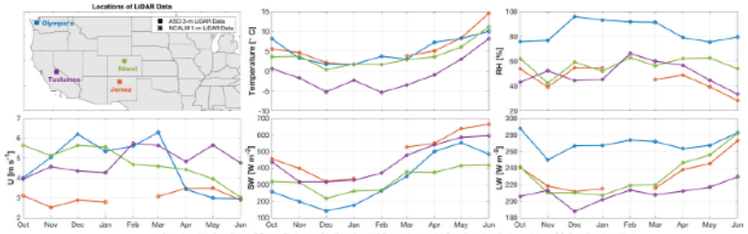


Figure 6: Mean monthly averages of meteorological conditions from four different environments

LiDAR Data

- **Olympic's WA:**
  - ASO: (3 m)
- **Tuolumne, CA:**
  - ASO: (3 m)
- **Jemez, NM:**
  - NCALM: (1 m)
- **Niwot, CO:**
  - NCALM: (1 m)

Categorizing North Facing and South Facing Forest Edges

Using 3 different methods:

1. Distance from Canopy
   - *3,6,…,30-m from the canopy*
2. Tree Height (H)
   - *0.5H,1H,2H from the canopy*
3. Sky View Factor
   - *Determine a threshold fraction of the sky that's visible*

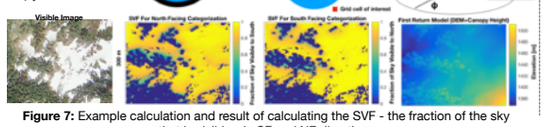


Figure 7: Example calculation and result of calculating the SVF - the fraction of the sky that is visible - in SF and NF directions

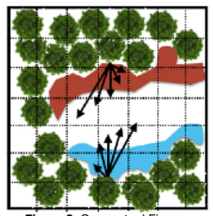


Figure 8: Conceptual Figure: Categorizing based on Distance & Tree Height

Preliminary Results

1. **North Facing (NF)** and **South Facing (SF)** edges (based on 15-m distance from canopy), along with **Open** and **Forested** areas shows unique snow depth distributions at Tuolumne (Figure 9)
2. At Tuolumne, **NF** shows more snow than **Open**, **SF Edges**, or **Forested** areas regardless of how we categorize the edge or spatial domain (Figure 10)

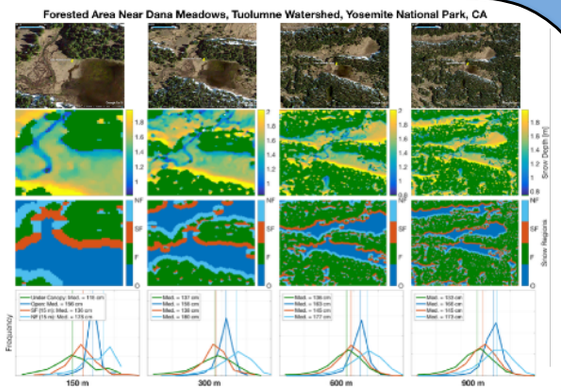


Figure 9: Snow Depth Distribution for 15-m search distance within various Bounding Box Sizes

Preliminary Results Continued:

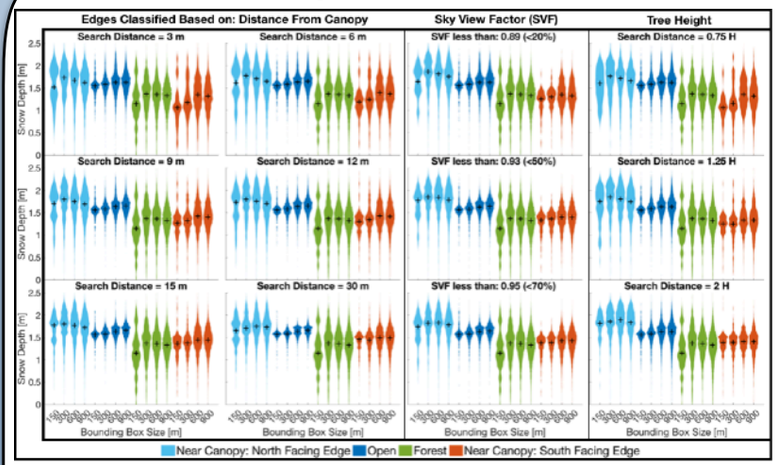


Figure 10: Snow depth distributions for various bounding box sizes (x-axis) and various sub regions (**Open**, **Forested**, **NF**, and **SF** forested edges) of that domain based on different methods for classifying the forest edges.

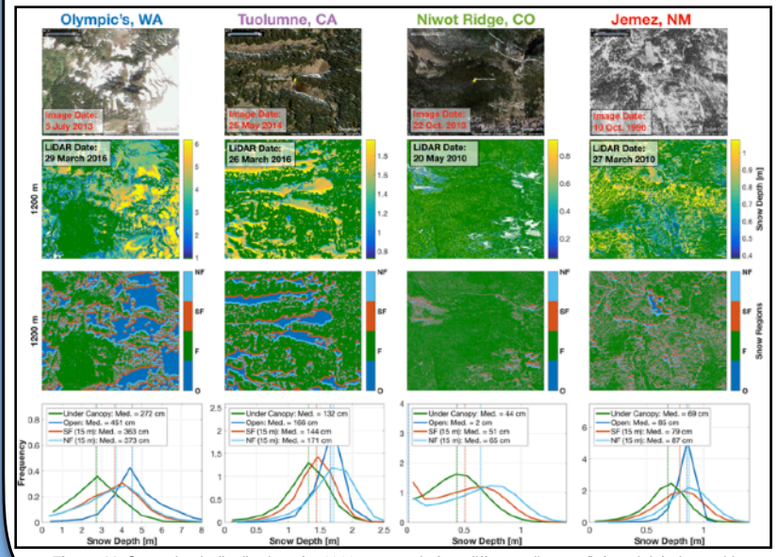


Figure 11: Snow depth distributions for 1200-m areas in four different climates (left to right) along with aerial imagery, snow depth maps and a classification map of forested, open and forest edges based on distance from canopy (15 m).

Conclusions

1. 20-50% more snow in the open than under the canopy across all study sites
2. Snow depth distributions were generally consistent when scaling the domain from 150 m to 1.2 km and when categorizing the forest edge based on various metrics: Distance from the canopy, SVF, and tree height (Figure 10).
3. **NF** shows more snow than **Open**, **SF Edges**, or **Forested** areas at all locations except the Olympics (Figure 11) which has little incoming shortwave radiation (decrease in forest shading) and more longwave radiation compared to other locations (Figure 6).

Future Work

1. We hope to soon begin answering how accurate snow depth is in forests from airborne LiDAR.
2. Determine how wind speed/direction lead to unique snow depth patterns.
3. Characterize spatial snow depth distribution within model grid cells in terms of canopy structure.

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